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SUBSTITUTE SPECIFICATION

A Micro-Machined Hot-Wire Flow Sensor for Spirometer

Background of the Invention

In recent years, respiratory related illness like chronic cough, chronic bronchitis, gasping etc. is increasing due to the air pollution and environmental deterioration. The clinical use of some of the medicine may change or improve the respiratory functions of the patients. Generally speaking, the parameters are taken based on the normal and basic volume of the testees using respiratory measurement instruments to determine the static and dynamic lung data. The information is provided for the diagnosis, treatment and tracing, such as the early detection of the lung disease, determination of seriousness, assessment of effectiveness, field or environmental influences, application of medicine and risks of surgery. The present respiratory diagnosis instruments will mainly take measurements of the respiratory volume or flow.

Volume measurement is to collect the out-going air into a container and then measure the continuous change of volume. Respiratory measurement is to take the flow by a converter for the volume calculation. In the Johnson, AT, Bronzino, JD, Respiratory system, *The Biomedical Engineering Handbook*, Ch. 7, pp. 70 - 86, Bronzino JD. mentioned that the parameters taken in different conditions and periods will be treated by the sensor and processor for the diagnosis and judgment of the respiratory function. Those

direct data like tidal volume, TV at rest or sports and vital *capacity* by full play breadth can be thus obtained.

Other parameters like IRV, ERV, IC can be made out by calculation. FVC is taken by the similar principle, and so are FEV, PEF, MMEF and MVV.

While the method of measurement is by volume and flow calculation, the respiratory measurement will be directional as the design and usage being similar and the portable or desk top models will prevail, in terms of convenience and miniaturization. The flow models available nowadays are generally of four types:

1. Differential air pressure/velocity;
2. Thermal resistance;
3. Turbine meter; and
4. Ultrasonic flow meter.

U.S. patent No. 5,460,039 indicates that the system of measurement of air velocity will include the traverse and parallel thermal resistance to the direction of the air flow but with less convenience and portability. U.S. patent No. 5,460,039 shows that a one time-use and throw away respirator uses the air pressure data to calculate the volume.

The respiratory flow or volume instrument is rather different in functions from those velocity devices, due to the complexity of the respiration which includes the saturated vapor and ionic compound. The features of the instrument will change as time goes by while the flow types are used in a relatively simpler process.

Another thing is that the range of flow for the instrument is rather limited compared to the wide fluctuation of the human respiratory flows, from 0 to 14L/sec. This must be taken into consideration in the design. It is desirable that the intake piece is of sterilizable or abandonable type as it is used for breathing, which would be otherwise difficult for the present flow or pressure types.

To realize the miniature concept for these instruments and enhance the portability and lower the cost, the measurement element, in addition to other parts, must be low in power consumption and high in precision, a difficult requirement for the popular measurement elements. There is a great demand for the elements of miniature size, low consumption of power, and precision.

Brief of the Invention

Based on the above requirements, the invention is related to the application *of* the micro electromechanical technology to make the elements miniaturized and modularized with the aim to lessen the weight of the relative instrument and make portability possible. With lowered cost in production and material, it is easy for manufacture. In addition, this type of the instrument will be available for combination with other sensors of similar use to widen its application.

Therefore, the product is termed the micro-machined hot-wire flow sensor for spirometer. The instrument has a crystal chip, a resistance with connection pads;

the chip area will be smaller than 2500x2500 $(\text{micrometer})^2$ in size, the resistance will be 1 to 1000 ohms, on the line width will be 5 to 1000 micrometers.

Also this invention includes the method of making such device, including at least the following:

(a) provide a chip base;

(b) surface preparation, which includes

(1) step to deposit a metal layer on top of the isolation;

(2) etching out the deposited metal layer which is outside the pattern;

(c) step to etch the chip base;

(d) step to make the connection pad for the resistance.

The flow sensor will have single or bi-directional capability of measurement according to the number of resistance elements on the crystal chip base, together with the processor, respiratory pipe, liquid crystal LCD display and other devices, in particular for the portable or desktop type.

Detailed Explanation of the Invention

Unlike other air flow measurement devices, the respiratory functional measurement has a lot of limits and therefore some potential problems in operation. The elements must

have sufficient mechanical strength and be properly mounted without damage or deformation due to the high speed flow of air. The devices shall not block the respiratory airflow with excessive back pressure.

The measuring elements, in any type of instrument, must have stable output and sensitivity to ensure accurate measurement. Otherwise problems like compensation may arise in connection with the temperature and composition of the airflow. The dust particles, drugs and salt in the breath are likely to settle on the surface of the sensor, causing pollution and a drift of features and a need for compensation. The surface pollution, beside the above mentioned problems, will be risky in that infective diseases may spread. Therefore, the design of the detection part will be preferably a sterilizable or abandonable type. Water is one of the substances in the breath, which will decrease the sensitivity, because it condenses in the instrument and reduces the effective working area unless the instrument is warmed up to close to or above the body temperature. The working range of the respiratory measurement is quite wide from the static situation to the maximum of sportsman. To keep certain precision in a wide dynamic range, different piecewise linear or analysis modules may be required in design.

This invention takes the detail consideration for the production and the selection of materials to improve the characteristic of the instrument, which is quite different from

the models mainly by improvement of the signal process. The instrument is safe, economical and easy to use.

A thermal tachometer has the advantages of being easy to use, light, portable, reliable, easy to clean and relatively cheap.

The invention is explained with reference to the making of a semiconductor device. The thermal micro sensor is built on the chip base. The semiconductor, in addition to increasing the precision, can be used for the electronic circuit as well as the sensing element. It is an intelligent instrument with less complexity on the external circuit, and decreased noise interference.

Two types of modules and sensors are considered. One is abandonable type using low cost materials, which is quite simple in design and needs little protection. The type is intended for short time or simple measurement. Another type is multifunctional with compound modules, which needs more protection and operates in relatively strict conditions with reliability and performance as the main considerations.

For the multifunctional type using a thermal sensor, there are some special requirements like the advantages of inertia, are low power consumption, and being miniature, modularizable, array able, simple and productive. To prevent passivation and skewing, and provide non-reactiveness to fluid material, a noble metal, semiconductor or even platinum will be used. If the sensor is designed for one time use and abandonment, common metal like nickel or chrome may be considered. As for the power consumption, the

common sensors have power consumption of a couple or a dozen watts, and a working temperature of several hundred degrees to provide required sensitivity. The invention has done some improvements in the regard that it is not feasible to the portable models.

The following will be considered as to raise the resistance value, or to reduce the current through the sensor so as to lower the heat generation in a controlled manner.

FIG. 1 shows the details of one direction, respiratory measurement for the instrument. The resistor 1 will be in a repeating pattern in the circuit to be based on the glass 3; pads 2a and 2b are coupled with the ends of the resistor 1. Altogether resistor 1, pads 2a and 2b and chip base 3 form the single direction measurement instrument.

FIG. 2 shows one side of the single direction respiratory measurement instrument. The glass, Corning 7740, is prepared for the-base 4; the isolation layer 5 (silica) is produced by wet oxidation; to follow, surface or base treatment will be carried out. The surface treatment by evaporation is to deposit the evaporated alloy of chromium (adhesion layer 6) and platinum (growing layer 7) on the glass base in the thickness of 500 angstrom for chromium and 2000-angstrom for platinum; or to put chrome layer 6 on the base 4 and then deposit platinum layer 7 on to layer 6. The wet etching process will proceed in order to remove the unwanted layer 6 and layer 7 (parts not required in design pattern) to finally form the resistive element as per the design diagram and wire layout. The following step will be decided according to whether the

device is for one time use and the silica protective layer and the connective pad would be made (not shown in the Figure).

To reduce the heat capacity of the thermal wire, a bulk micromachining procedure must be made on it, by way of wet etching (diluted hydrofluoric acid) or dry etching (active ion) as a base bulk treatment. The process does not require exposure or development as the resistant element (thermal wire) itself is resistive and will align automatically.

As shown in FIGS. 3 and 4, we can see the top and front view of the bi-directional respiratory flow measurement device. There are two major principles for the bi-directional respiratory measurement device: self heating and non self heating. In the Figures is shown the non self heating detection element without a protection layer. Here we have chip 8, two non self heating resistance elements 9, 10, connection pads 9a, 9b and 10a, 10b, and thermal wire 11, to be joined to the chip 8. From FIG. 4 we have there is an isolation layer 12 on the base 8, and there is a void 13 as a result of base 8 fabrication (sketch of deposition layer omitted). Under the condition of non self heating balance and the air flow does not pass module 14, the temperature at both the ends of the self heating wire 11 and the non self heating resistance elements 9 and 10 (higher than body temperature) are the same; and when there is air flow passing from the left to the right of the sensor module 14 causing temperature changes at the non self heating resistance elements 9 and 10 (the temperature at the exit on the right side of the

resistance is higher than the intake on the left) . As a result, the difference of the resistance values can be adopted for calculating the parameters of the respiratory flow as has been done in the fixed voltage. circuit.

FIG. 5 is the front view of the bi-directional thermal respiratory measurement device with a protection layer. The device is a self heating module 22, having chip base 21, isolation layer 15, two self heating resistance elements 16 and 17, protection layer 20 and one shielding layer 19. The principle is similar to that of the non self heating type i.e. there is a difference between the measured values of the two resistances due to the existence of the shielding layer 19. It is also possible to make a design for a temperature regulating circuit for the calculation of the air flow parameters.

In the selection of the materials for the device, the chips may be, in case of the low cost or one time use device, glass, silicon or ceramic materials. For the growing layer between the-chip base and the metal layer, chrome or titanium can be used. Copper or aluminum can be used for connection pads.

As for the processing procedures like oxidation, wet or dry etching, chemical stacking, evaporation deposit and splashing deposit, there is no limit whatsoever except the differences by choosing different materials or resistances.

The only limit is that the device will be miniaturized in that the chip area will be less than 2500x2500 (micrometer)^2, the wire width will be 5 to 100 micrometers, best 10 to 50 micrometer, and the resistance will be 1 to 1000 ohms. The film obtained under

these conditions will have a thickness of 0.1 to 0.5 micrometer, best at 0.1 to 0.3 micrometer, a working current of 1 to 100 milliamperes, and a working temperature of 40 to 200 degrees, best at 40 to 50 degree.

As the requirements of conditions and sensitivity change, the wire width and resistance angle may be widened or revised, or to increase temperature compensation in the design, or to increase the unit density of the thermal wire for a better efficiency or higher resistance, thus higher sensitivity.

The following is the sensor elements Hi-501 (Ni-Pt) found in the market, on which the comparison is made on the power consumption (example A):

	Resistance (ohm)	Sensor area (sq.f)	Wire volume	Ther.capa.
Hi-501	1.9	2.87mX10-7	3.93X10-12	148.8
Example A	1474	3.3X10-7	2.64X10-14	1

The invented device has a small body and thus a low heat capacity and temperature decrease; with an increased sensing area the sensitivity is higher to offset the effect of decreased temperature. ■

Another sensor module (example B) has been compared with the market sensor Hi-501:

	Resistance (ohm)	Sensor area (sq.O	Wire volume	Ther.capa.
Hi-501	1.9	2.87mX10-7	3.93X10-12	148.8
Example B	20	6.0X10-7	1.2X10-13	4.55

Example B is the revised version of the Example A, which has a higher resistance than Hi-501 and a reduced current and heat. The sensor area is larger than Hi-501 and more sensitive to the flow speed, thus offsetting the effect of decreased temperature.

The modularized components will make the device more powerful just as other models with additional sensors or modules to increase the functions of measurement and the value of the device. The respiratory measurement device made for this purpose will be used not only in the massive screening check but also in the field preventive procedures and family care having the very high practicable value.

Brief Explanation of Drawings

FIG. 1 is the micrograph of the single direction micromachined hot wire flow sensor for spirometer.

FIG. 2 is the side view of the single direction micromachined hot wire flow sensor for spirometer.

FIG. 3 is the plan of the bi-directional micromachined hot wire flow sensor for spirometer.

FIG. 4 is the front view of FIG. 3.

FIG. 5 is the front view of the bi-directional micromachined hot wire flow sensor for spirometer.